FERMI
national accelerator laboratory

TM-567
0428.000

Short Sample Test Data III

M. E. Price, R. Yamada, R. Pighetti, and R. Barger

March 24, 1975

Recent wires which have been short sampled include Fermilab -11 cables, single strands of MCA wire Billet #239 and cabled wires made from these strands, a 36 strand square MCA cable, a French cable, a Brookhaven braid, a Furukawa solid, and solders.

A few comments about the following tables. J_c is current density in superconductor only. I_{eff} is current density in rectangular envelope including copper, superconductor, solder and any air pockets.

I. Equipment Change

There have been no procedural changes in recent short sample tests, but major equipment changes have been made. A Transrex 500-5 power supply, which give 5000 amp at maximum, is now used to supply current to the samples instead of using two H.P. 6463's in parallel. An automatic Helium level control was installed as well as additional temperature sensors, another liquid level probe, and a field detector. We are also now hooked into the Helium recovery system when it works.

II. Fermilab 11 Strand Wire

Five samples of Fermilab 11 were tested. These are cables made of IGC 25 mil strands, and made into cables at the University of Wisconsin. Their results are shown in Table I. The samples are one without solder, two soldered ones, one keystoned, and a broken one. The first sample had no solder, only 11 wires loosely twisted together. This sample showed lower quench currents than others as expected but same J_c at $10^{-12}\Omega$cm and less current shaving than the others. Two soldered samoles were tested - one bifiliar wound and the other hairpin and the results were practically identical. A sample was keystoned, then tested, and gave the same results.

This wire shows an improvement over the Supercon 11 strand, but it is somewhat worse than MCA 11 strand. See Table I and Figure 1. The final sample had a broken strand, but there was about two inches overlap. The quench current was lowered by only 3∿4%.

III. Series of MCA Single Strands

We tested two series of single strand MCA samples. All the wires in a given series had the same treatment until the final drawing, but the heat treatments of the two series were different. The first consisted of #8 - #12, were .037", .030", .025", .020", and .015" in diameter and had the long heat treatment during drawing process at .114". The second consisted of #13 - #16, were

.030", .025", .020", and .015" in diameter, and had the long heat treatment at .078".

A plot of cross section vs current at 50 KG and at $5 \times 10^{-13}\Omega$cm gives a straight line for each series. I_{eff} is also indicated on the plot. The number with parenthesis is I_{eff} if each wire were enclosed in a square area and without is I_{eff} for the strand as is. The resistance of copper was about $1.8 \sim 1.9 \times 10^{-6}\Omega$cm. It looks like good wire. See Table II and Figures 2 and 3.

IV. MCA 7 Strand and 11 Strand Wires

Six 75 x 150 samples, made from previous MCA .037" strands were tested. They were an unsoldered, a soldered, two turkesheaded and two keystoned ones. The results are summarized in Table III and in Figure 4.

The final keystoned form carried the same current as 7 times one strand. However, turksheaded samples before keystoning carried from 400 to 600 amps more. This change in critical current values may be due to cold working of turksheading and keystoning, or they may have come from different ends of a spool. A keystoned sample was tested, resoldered, then tested again with no change in the critical current. A turksheaded sample had all measurements repeated and all results were the same.

The 11 strand 50 x 150 wire, made from 25 mil diameter strands, was tested using an unsoldered and a soldered sample. The results are shown in Table IV. The soldered one carries 60 amps more than 11 x current in a single strand. The unsoldered one carries 10% more. They may have come from different ends of a spool. We have not tested a keystoned sample yet.

The design current at 50 KG for the seven strand wire is 3500 amps while the keystoned samples tested had only 3270 amps. The 11 strand sample with a current of 2390 amps at 50 KG is about 60 amps over specification. Although the seven strand sample, after keystoning at Fermilab, does not meet design, both MCA cables are probably the best wires tested so far.

V. Other Wires

The results of miscellaneous cables are listed in Table V. The square MCA cable (HI conductor) is 91 mils x 91 mils, has 36 strands with superconductor and a center strand which is all copper, and has Cu:S.C. ratio of 1.8:1.

I_{eff} at 50 KG at $10^{-12}\Omega$cm is 50 kA/cm^2. This MCA square cable seems good and might be worth looking into.

The French wire was received without any information at all. Six strands containing superconductor were twisted around a center all copper strand. Six of these small cables were twisted together and shaped into a rectangle to form the final cable. No solder was used. Microscopic examination revealed 37,620 superconductor filament each approximately 11μ diameter. Therefore J_c is only an estimate. If the diameter is 10μ or 12μ J_c would change by 15%. Although the sample has a high critical current, 4440 amps of 50 KG, the cross section is large and J_c and I_{eff} do not compare with other samples tested.

The result of the short sample test on the Furukawa solid wire Type D is a low critical current. This wire has 33,000 7.3μ filaments and CuNi shieths. The cross sectional area of superconductor in the Furukawa is within 2% that of MCA 7 strand cable. However, the critical current, J_c and I_{eff} are all about half that of MCA 7 strand cable. The amount of current sharing is much greater than for MCA and Fermilab cables.

The final wire we have tested recently is a sample of Brookhaven braid, approximate dimensions of .8" x .030". We were told there were 186 strands each with 361 filaments 12μ in diameter. Microscopic examination revealed the filament diameter to be ∿7μ. This corresponded with calculations based on Cu:S.C. ratio of 1.25:1. Therefore J_c was calculated based on a filament diameter of 7.1μ. The critical current for the Brookhaven braid is higher than that of the MCA cables, but J_c is only 3/4 as much and due to braid structure I_{eff} is 1/2.

VI. Superconductivity of Solders

In addition to testing the wires, we have run resistance measurements and short sample tests on Koester 50/50 and 60/40 solders to estimate their effect on the resistance measurement of superconducting wire.

For both types of solder the resistance goes to zero at approximately 6.5°K. The resistance curves are shown in Figure 6. The resistivity at different temperatures are shown below.

	Room Temp (300°K)	12°K	7.5°K	6.5°K	P_{300}/P_1
50/50 Solder	14.1×10^{-6}	2.6×10^{-7}	2.3×10^{-7}	2.9×10^{-8}	54
60/40 Solder	14.2×10^{-6}	5.3×10^{-7}	4.9×10^{-7}	4.8×10^{-7}	27

The resistivity of 60/40 solder at 12°K is about 14 times that of copper with resistivity ratio $P_{300}/P_{12}=50$. If we assume there is 20% 60/40 solder in the cross section of wire, it will affect the resistivity ratio of copper by 4%.

The short sample test data is shown in Figure 5. At zero current 50/50 solder becomes superconducting below 0.6kG, while 60/40 solder below 0.5 kG. At zero field 50/50 solder has a current density of 10kA/cm^2, while 60/40 has 9 kA/cm^2. The resistivities of these solders are respectively about 2 and 4 x $10^{-7}\Omega$cm above transition field. These resistivities were measured by short sample test method, increasing magnetic field beyond the transition field.

		40KG	50KG	60KG	Resistivity at Quench	at 50 KG J_c (KH/cm^7)	at 50 KG I_{eff} (KH/cm^2)
Unsoldered (bifiliar) Jan 21	Quench		2030	1650		192	42
	2×10^{-12}		–	–		–	–
	10^{-12}		2020	1630	1.3×10^{-12}	191	41
	5×10^{-13}		1920	1550		181	39
Soldered (bifiliar) Jan 21	Quench		2110	1700		199	43
	2×10^{-12}		2040	1650	5×10^{-12}	192	42
	10^{-12}		1970	1620		186	40
	5×10^{-13}		1830	1540		173	37
Soldered (hairpin) Jan 22	Quench		2120	1710		200	43
	2×10^{-12}		2050	1700	5×10^{-12}	193	42
	10^{-12}		1930	1630		181	39.5
	5×10^{-13}		1830	1550		173	37
Soldered (hairpin broken strand) Feb 7	Quench	2540	2060	1680		194	42
	2×10^{-12}	2510	2040	1650	3×10^{-12}	192	42
	10^{-12}	2320	1840	1530		174	37.6
	5×10^{-13}	2040	1610	1370		152	33
Keystoned (hairpin) Feb 5	Quench	2630	2150	1740		203	44
	2×10^{-12}	2620	2130	1720	3×10^{-12}	201	44
	10^{-12}	2560	2000	1630		189	41
	5×10^{-13}	2410	1850	1490		174	38
11 x IGC Value for Single Strand	Quench		2180	1740	3×10^{-11}	206	45

TABLE I Fermilab 11 Strand Wire (made from IGC strands)

TM-567
0428.000

Billet #239	dia.(")	$\frac{P_{300}}{P_{12}}$		30	40	50	60	at 50 KG J_c (KA/cm²)	I_{eff} (KA/cm²) Strand	I_{eff} (KA/cm⁷) Square
#8	.037	71	Quench	728	581	472	381	191	68	53
			5×10^{-13}			462		187	67	53
#9	.030	71	Quench	475	379	310	252	190	68	53
			5×10^{-13}	463	374	303	246	186	66	52
#10	.025		Quench		261	214	174	189	68	53
			5×10^{-13}		258	212	170	187	67	53
#11	.020	62	Quench	213	173	144	117	199	71	56
			5×10^{-13}	202	163	133	107	184	66	52
#12	.015	54	Quench	110	92	76	62	186	67	53
			5×10^{-13}	110	92	75	60	184	66	52
#13	.030	87	Quench	435	348	285	230	175	63	49
			5×10^{-13}	433	341	279	226	171	61	48
#14	.025	68	Quench	296	241	196	162	173	62	49
			5×10^{-13}	296	241	192	160	170	61	48
#15	.020	62	Quench	195	160	132	108	182	65	51
			5×10^{-13}	191	157	127	104	175	63	49
#16	.015	112(?)	Quench	118	97	81	67	199	71	56
			5×10^{-13}	103	83	67	56	165	59	46
Billet #240	.037	73	Quench 5×10^{-13}	698	558	451	363	182	65	51

TABLE II Series _f MCA Single Strands

	$\frac{P_{300}}{P_{10}}$		40KG	50KG	60KG	P at Quench	J_c (KA/cm^7) at 50 KG	I_{eff} (KA/cm^2)
Unsoldered 80 x 155 March 5	50	Quench	4170	3440	2770		198	43
		2×10^{-12}	3860	2910	2340	10^{-11}	168	36
		10^{-12}	3600	2550	2170		147	32
		5×10^{-13}	3370	2320	1920		134	29
Soldered 85 x 150 March 5	52	Quench	4080	3390	2800		196	41
		2×10^{-12}	4080	3370	2780	2×10^{-12}	194	41
		10^{-12}	4010	3260	2720		188	40
		5×10^{-13}	3860	3120	2640		180	38
Turksheaded I 75 x 147 March 5	51	Quench	4460	3760	3220		217	53
		2×10^{-12}	4460	3760	3190	2×10^{-12}	217	53
		10^{-12}	4370	3670	3120		212	52
		5×10^{-13}	4290	3570	3020		206	50
Turksheaded II March 11	48	Quench	4690	3970	3390		229	56
		2×10^{-12}	4670	3940	3370	3×10^{-12}	228	55
		10^{-12}	4580	3860	3280		223	54
		5×10^{-13}	4490	3760	3180		217	53
Keystoned I 75 x 155 63.6 x 155 Start of keystoning March 7	46	Quench	4050	3390	2790		196	49
		2×10^{-12}	4030	3340	2750	3×10^{-12}	193	48
		10^{-12}	3930	3260	2660		188	47
		5×10^{-13}	3800	3180	2580		184	46
Keystoned II Start C-3-10 Inner	44	Quench	4060	3390	2820		196	49
		2×10^{-12}	4060	3370	2780	2×10^{-12}	194	49
		10^{-12}	4010	3270	2720		189	47
		5×10^{-13}	3860	3140	2640		181	45

TABLE III MCA 7 (37 mil strands Billet #239)

	$\frac{P_{300}}{P_{10}}$		40KG	50KG	60KG	P at Quench	at 50 KG J_c (KA/cm^7)	I_{eff} (KA/cm^2)
Unsoldered	45	Quench	3460	2960	2540		237	61
March 7		2×10^{-12}	3370	2830	2420	4×10^{-12}	227	59
50 x 149		10^{-12}	3260	2670	2340		215	56
$4.806 \times 10^{-2} cm^2$		5×10^{-13}	3060	2480	2240		199	52
Soldered	46	Quench	2920	2450	2050		197	52
March 12		2×10^{-12}		2450	2050	2×10^{-12}	197	52
49 x 148		10^{-12}	2910	2390	1990		192	51
$4.679 \times 10^{-2} cm^2$		5×10^{-13}	2850	2290	1900		184	49

TABLE IV MCA 11 (25 mil strands)

	P_{300}/P_{10}		40KG	50KG	60KG	Resistivity at Quench	J_c (KA/cm^2)	I_{eff} (KA/cm^7)
French L	185	Quench		5210	4350		146	40
Feb 5		2×10^{-12}		4540	3680	4×10^{-11}	127	35
.107 x .188		10^{-12}		4440	3570		124	34
Brookhaven	19	Quench	5020	4160	3270		155	25
Feb 6		2×10^{-12}	-	3950	3070	10^{-11}	147	25
.031 x .790		10^{-12}	-	3730	2920		139	24
		5×10^{-13}	4720	3420	2670		128	22
MCA HI	71	Quench	3530	3010	2520		205	57
(Sq.Cable)		2×10^{-12}	3530	2990	2510	2×10^{-12}	203	56
Feb 7		10^{-12}	3200	2630	2220		179	50
.091 x .091		5×10^{-13}	2820	2340	2000		159	44
Furukawa	52	Quench	2380	1990	1670		116	30
Solid, Type D		2×10^{-12}	1930	1660	1350	5×10^{-11}	97	25
March 6		10^{-12}	1830	1610	1300		94	24
.074 x .147								

TABLE V MISCELLANEOUS WIRES

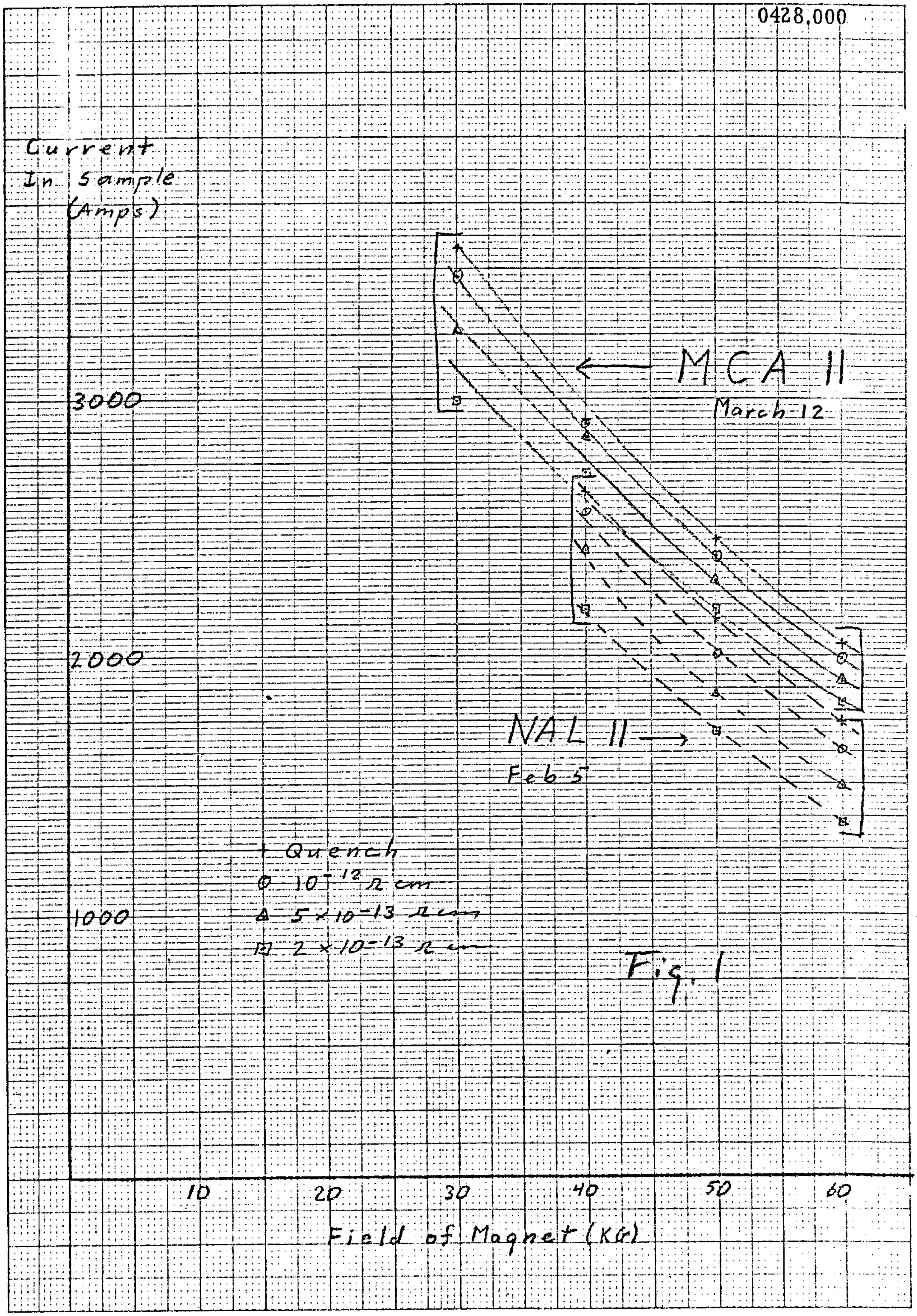

Current
In sample
(Amps)
3000
2000
1000
MCA II
March 12
NAL II
Feb 5
+ Quench
⊘ 10^{-12} Ω cm
△ 5×10^{-13} Ω cm
⊡ 2×10^{-13} Ω cm
10
20
30
40
50
60
Field of Magnet (KG)

Fig. 1

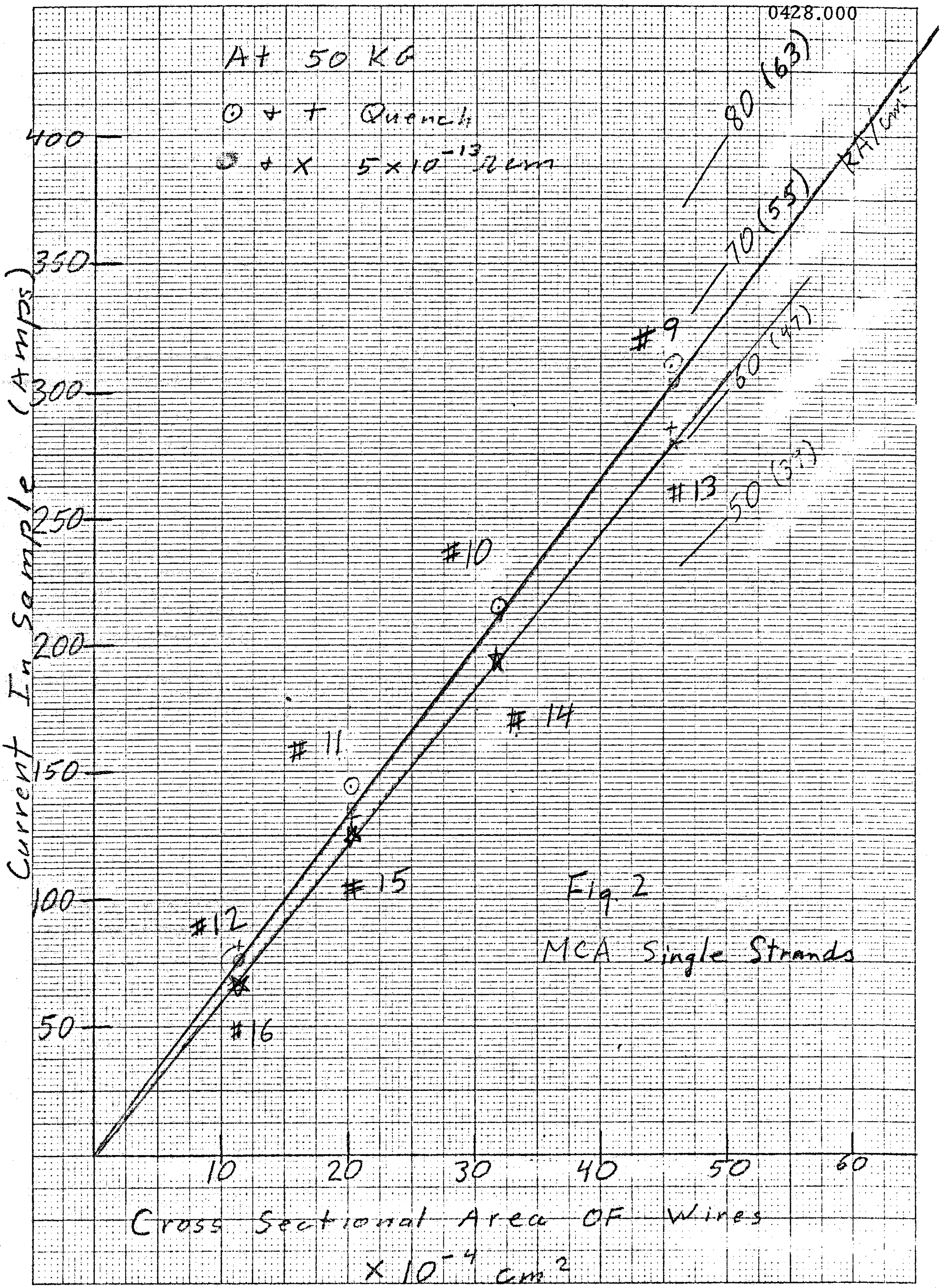


Fig. 2

MCA Single Strands

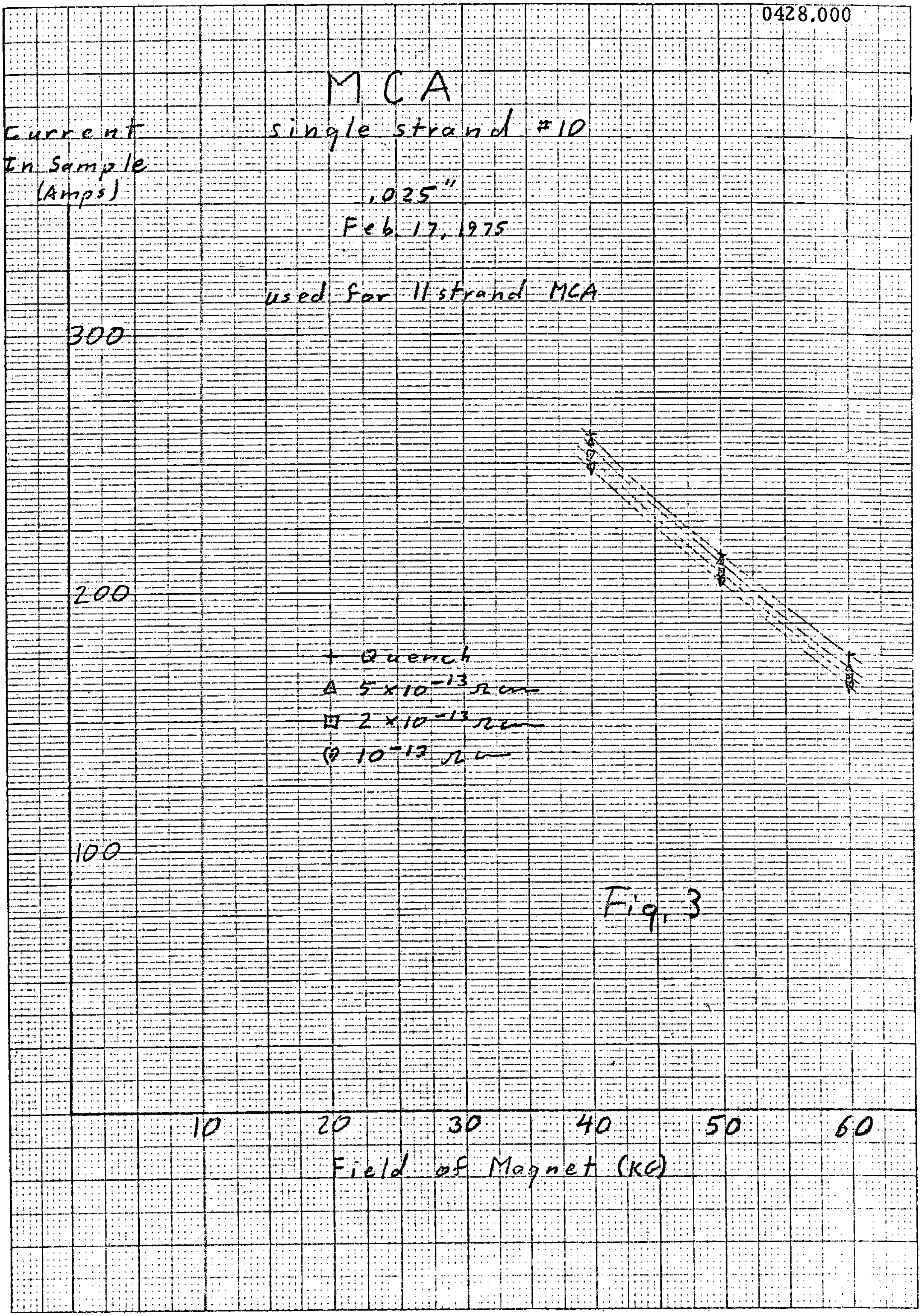

MCA
single strand #10
.025"
Feb. 17, 1975
used for 11 strand MCA
Current
In Sample
(Amps)
300
200
100
+ Quench
Δ 5×10⁻¹³ Ω cm
□ 2×10⁻¹³ Ω cm
○ 10⁻¹³ Ω cm
10
20
30
40
50
60
Field of Magnet (KG)

Fig. 3

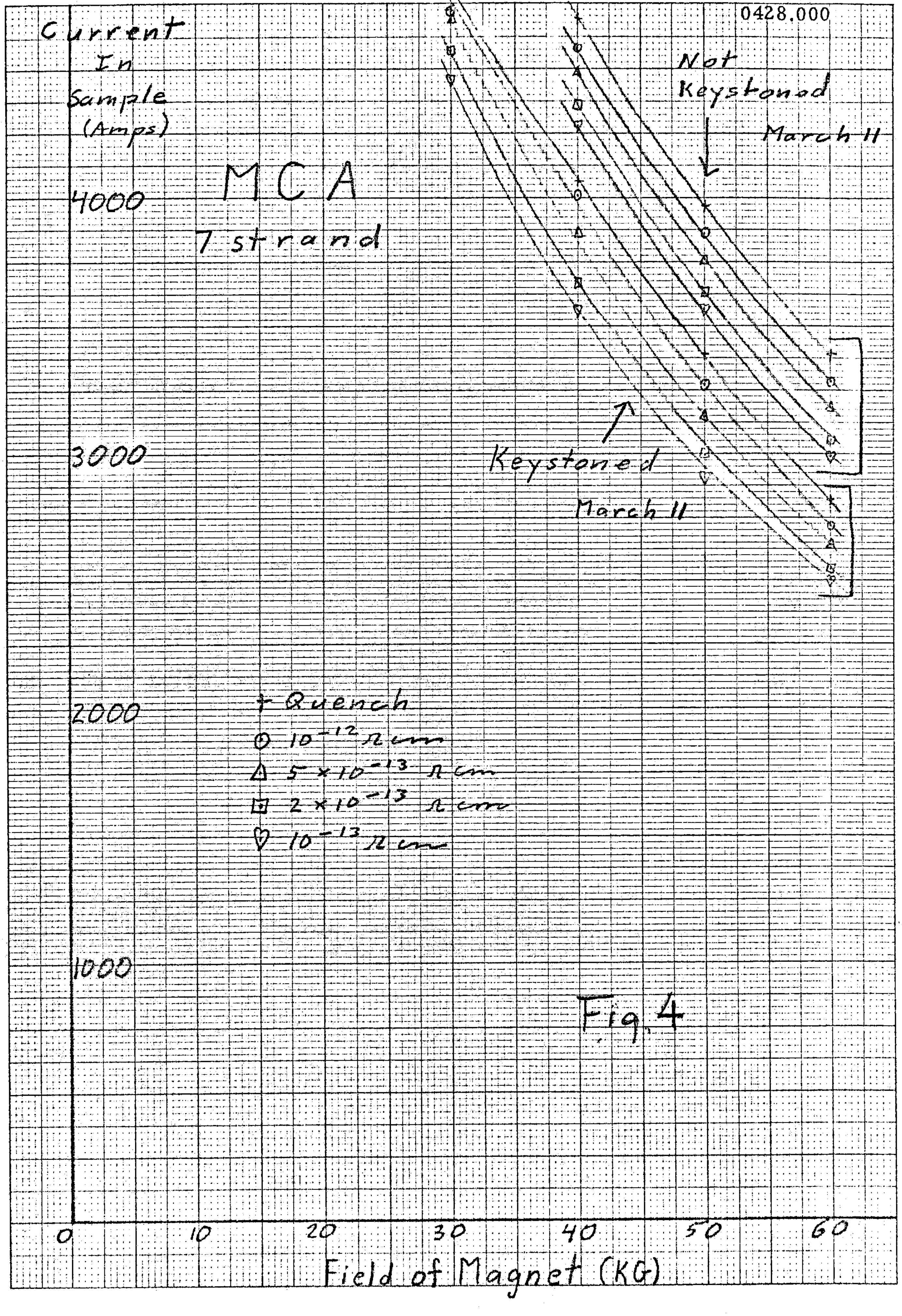
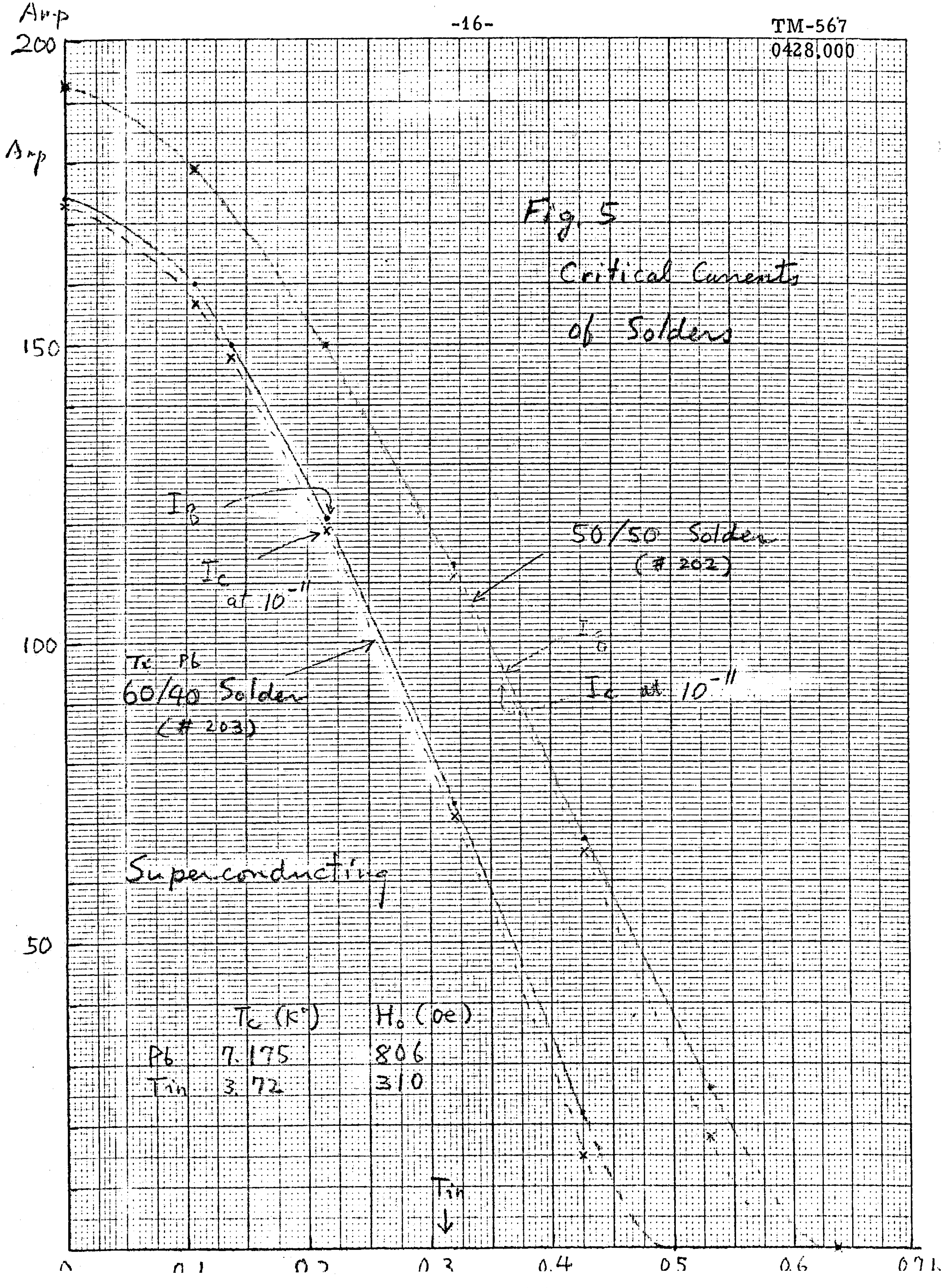

Current In Sample (Amps)
MCA
7 strand
4000
3000
2000
1000
Not Keystoned March 11
Keystoned March 11
+ Quench
⊙ 10^{-12} Ω cm
△ 5×10^{-13} Ω cm
⊡ 2×10^{-13} Ω cm
▽ 10^{-13} Ω cm
0
10
20
30
40
50
60
Field of Magnet (KG)

Fig. 4


Amp
200
150
100
50
Fig. 5
Critical Currents
of Solders
I_B
I_c
at 10^{-11}
50/50 Solder
(# 202)
I_B
I_c at 10^{-11}
T_c Pb
60/40 Solder
(# 203)
Superconducting
T_c (K°) H_0 (oe)
Pb 7.175 806
Tin 3.72 310
Tin
0
0.1
0.2
0.3
0.4
0.5
0.6

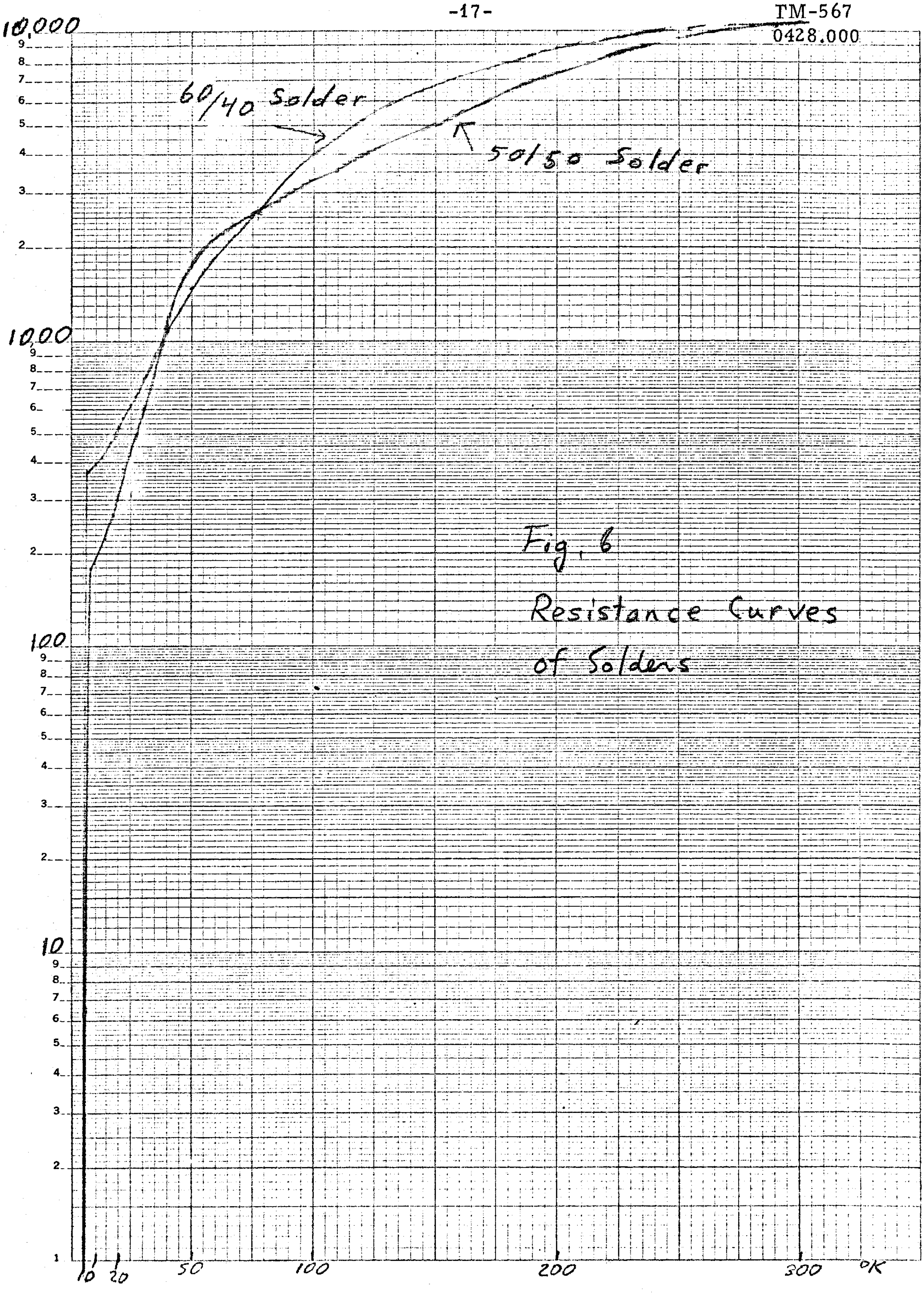


Fig. 6
Resistance Curves of Solders